TECHNICAL NOTE 370

A Predictive Model for Estimating Maximum Summer Stream Temperatures in Western Oregon

an J. Schloss

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A PREDICTIVE MODEL FOR ESTIMATING MAXIMUM SUMMER STREAM TEMPERATURES IN WESTERN OREGON

by

Alan J. Schloss[1]

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[1] Hydrologist, USDI Bureau of Land Management, Eugene, Oregon

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Land Managers often need to know maximum stream temperatures in order to make land use decisions. This paper describes a formula, developed empirically, which estimates maximum stream temperatures within approximately 3° F. The factors used in this formula are basin elevation, main channel length, stream order, and amount of shade.

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ABSTRACT

Land managers often need to know maximum stream temperatures in order to make land use decisions. This paper describes a formula, developed empirically, which estimates maximum stream temperatures within approximately 3° F. The factors used in this formula are basin elevation, main channel length, stream order, and amount of shade. The formula is applicable to forested regions in Western Oregon.

INTRODUCTION

The Bureau of Land Management (BLM) Eugene District Management Framework Plan commits the District to compliance with the State of Oregon's water quality requirements. Chapter 340 of the Oregon Administrative Rules sets standards for water temperatures in streams. These standards set an upper limit for temperature, above which no further temperature increase is permitted. In no case may the increase in water temperature be greater than 2° F. The maximum permitted temperature for the Willamette Basin is 58° F; for the mid-coastal basins the limit is 64° F.

To comply with the State standards a forest manager must be able to answer two questions: 1) how much increase in temperature can be expected from a management practice? and 2) what is the expected maximum summer temperature? The purpose of this study was to develop a formula to estimate maximum summer stream temperatures in forest streams in Western Oregon.

METHODS

The data used for this study were collected from the BLM's Eugene and Roseburg Districts, the Siuslaw National Forest, the Cottage Grove Ranger District of Umpqua National Forest, and the Lowell Ranger District of the Willamette National Forest. These sources best represent conditions on the Eugene District because the are similar in climate, topography, and geomorphology. Each agency provided records of maximum summer stream temperatures along with maps showing the location of each measurement. We also asked for streamflow when the temperature was taken, if available. All of the data were used in this analysis even though temperatures were taken for varied purposes.

Several hydrologists were asked what factors could logically be expected to affect maximum stream temperature. The following were selected because they were easily measurable: 1) basin elevation; 2) station elevation; 3) elevation at source; 4) main channel length; 5) total channel length; 6) basin size; 7) drainage density; 8) basin aspect; 9) channel slope; 10) stream order; 11) flow (cfs and cfsm), and 12) vegetative cover.

The flow factor nad to be dropped because there were very few data available. The vegetative cover was given a code of 1 (natural conditions (almost full cover); 2 (partial removal of cover), and 3 (total or almost total removal of cover). This was a subjective rating and included information obtained by telephone coversations with local personnel. Basin aspect was converted to the number of degrees away from southwest, the aspect receiving the maximum summer solar radiation. All other factors were measured using the National Handbook of Recommended Methods for Water-Data Acquisition (USDI Geological Survey, 1977). Measurements were made on USGS 15-minute quadrangles.

The data were analyzed using a step-wise linear regression. Under this approach each factor is regressed against temperature. The variable with highest correlation is accepted for the explanatory equation. Each of the other variables is then regressed against the first variable, and the one accounting for the most additional variation is accepted for the equation. This procedure is continued until no remaining variable meets the statistical requirements set. An "F to enter" level of 2.7 was used. This is approximately the 10 percent probability level for testing the significance of an additional variable under the usual linear regression analysis for 1 and 150+ degrees of freedom. A matrix printout of residuals was studied to look for non-linear relations and several factors were subsequently analyzed using logarithm, power, or exponential variables. Variables generated as the product of single variables were also examined for significance.

Several factors were found to be significant and were used to develop a formula. Elevation is known to be a factor in determining stream temperature because it is the prime factor influencing ground water temperature which enters the streams. Since Eugene District land is mostly below 2,000 ft. elevation, and almost 80 percent of the measurements were made below that elevation, the range of elevation data was relatively small, resulting in a significance which was slightly lower than that for the "F" of 2.7. In many cases, however, reasonable estimates of stream temperatures would require use of that variable, so it was entered into the equation.

A recent study (Smith, 1981) shows a tendency for streams to equalize temperature if they have the same shade characteristics. To see if this theory applied, we analyzed the logging code for large basins (greater than 5 mi^2) and small basins (less than 5 mi^2). We found that logging code was not significant for the larger basins. This would verify the theory that longer travel (e.g., larger basins) tends to eliminate or minimize the effect of shade removal upstream. I chose one mile as maximum distance where the effects of shade removal would have a significant effect. I then converted the 1, 2, 3 logging code to percentage of area where shade is missing.

RESULTS

The following equation was developed to predict maximum stream temperature:

$$T = 53.543 - 0.000712\ E + 0.597\ L + 1.217\ O + 3.266\ (S/50 + 1)$$

Where: T = Maximum summer temperature, ^{O}F
E = Elevation, ft.
L = Main channel length, mi.
O = Stream order
S = Shade code

This equation yields an "F" ratio of 36.62, and a standard error of estimate of 3.62^{O} F. I have tested the formula against temperature measurements taken in the summer of 1984. The resulting analysis between predicted and actual values showed a standard deviation of 3.19 and a correlation coefficient of 0.69 This formula should predict maximum summer temperatures within ±3° F. More data would yield a more accurate formula.

APPLICATION

Until a more accurate model is developed, it will be necessary to estimate summer stream temperatures to predict impacts and make decisions about timber harvesting. This formula can be used to estimate temperature within plus or minus 3° F. The formula can also be used to obtain changes in temperatures due to shade removal. Far more accurate estimates of changes in temperature can be obtained by using methods by Brown (1970).

To use this formula, obtain the following information:

1. Basin Elevation: Read the elevation at the point of interest and at the headwall of the main stream. The average of these is a close estimate of basin elevation. Enter in ft.
2. Total Channel Length: Measure the distance from the headwall of the main stream (largest stream) to the point of interest. Enter in miles.
3. Enter the stream order at the point of interest. Order 2 is where two order 1 streams join; order 3 is where two order 2 streams join, etc.
4. From aerial photos or personal knowledge, estimate the percent of stream length, within one mile of the point of interest, that does not have complete shade cover. Consider partial shade as no cover. Enter as whole number.

The formula can be calculated by hand or programmed into a computer. I have included the programming instructions for a HP-41C in Appendix 1.

Using these methods, the maximum expected stream temperature can be estimated within 3° F. (R^2 = .8938)

The equation is applicable to forested regions in Western Oregon. However, the procedures used to develop the equation should be applicable in other regions.

LITERATURE CITED

Brown, George W., 1970. Predicting the effects of clearcutting on stream temperature. Journal of Soil and Water Conservation, 25(1), 11-13.

Smith, Kent, 1981. Temperature Study on Mouse Creek, A Class Three Stream. Unpublished Report. U.S. Forest Service, Cottage Grove Ranger District, Umpqua National Forest.

USDI Geological Survey, 1977. National Handbook of Recommended Methods for Water Data Aquisition, Office of Water Data Aquisition, Reston, Virginia.

APPENDIX I

Program Instructions
for HP 41CV

```
01  LBL TEMP
02  53.5432
03  STO 01
04  ELEV FT.
05  Prompt
06  .000712039
07  X
08  STO 02
09  Chan Length MI
10  PROMPT
11  .596513
12  X
13  STO 03
14  ORDER
15  PROMPT
16  1.21717
17  X
18  STO 04
19  Shade % Cut
20  Prompt
21  2
22  X
23  100
24  /
25  1
26  +
27  3.266613
28  X
29  RCL 01
30  +
31  RCL 02
32  -
33  RCL 03
34  +
35  RCL 04
36  +
37  END
```

APPENDIX 2

Results of Regression

Multiple R	0.7989
Std. Error of Est.	3.63

Analysis of Variance

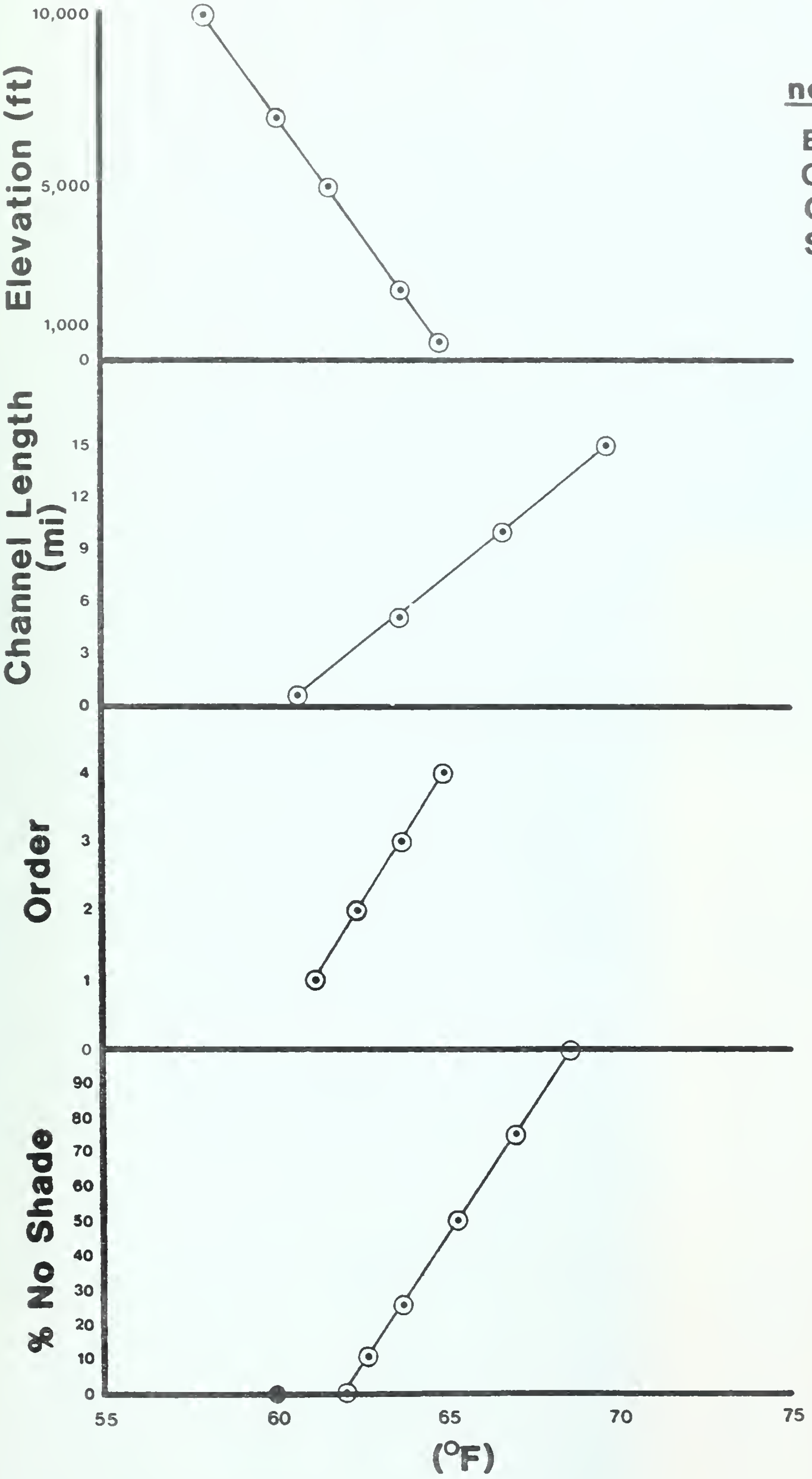
	DF	Sum of Squares	Mean Squares	F Ratio
Regression	4	19.2986E+03	48.2465E+01	36.62
Residual	83	10.9359+02	13.1758E+00	

Variables in Equation

Variable	Coefficient	Std. Error	"F" to Remove
Constant	53.5432E+00		
Elevation	-71.20039E-05	48.1890E-05	21.83E-01
Channel Length	59.6513E-02	12.2183-02	23.84E+00
Order	12.1717E-01	42.7437E-02	81.09E-01
Shade Code	32.6613E-01	78.6439E-02	17.25E+00

Appendix 3

Sensitivity of Variables



Value of non-tested variables

Elev = 2,000 ft
Chan Length = 5 mi
Order = 3
Shade Code = 25%

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